The

Kentucky Geological Survey

WILLARD ROUSE JILLSON
DIRECTOR AND STATE GEOLOGIST

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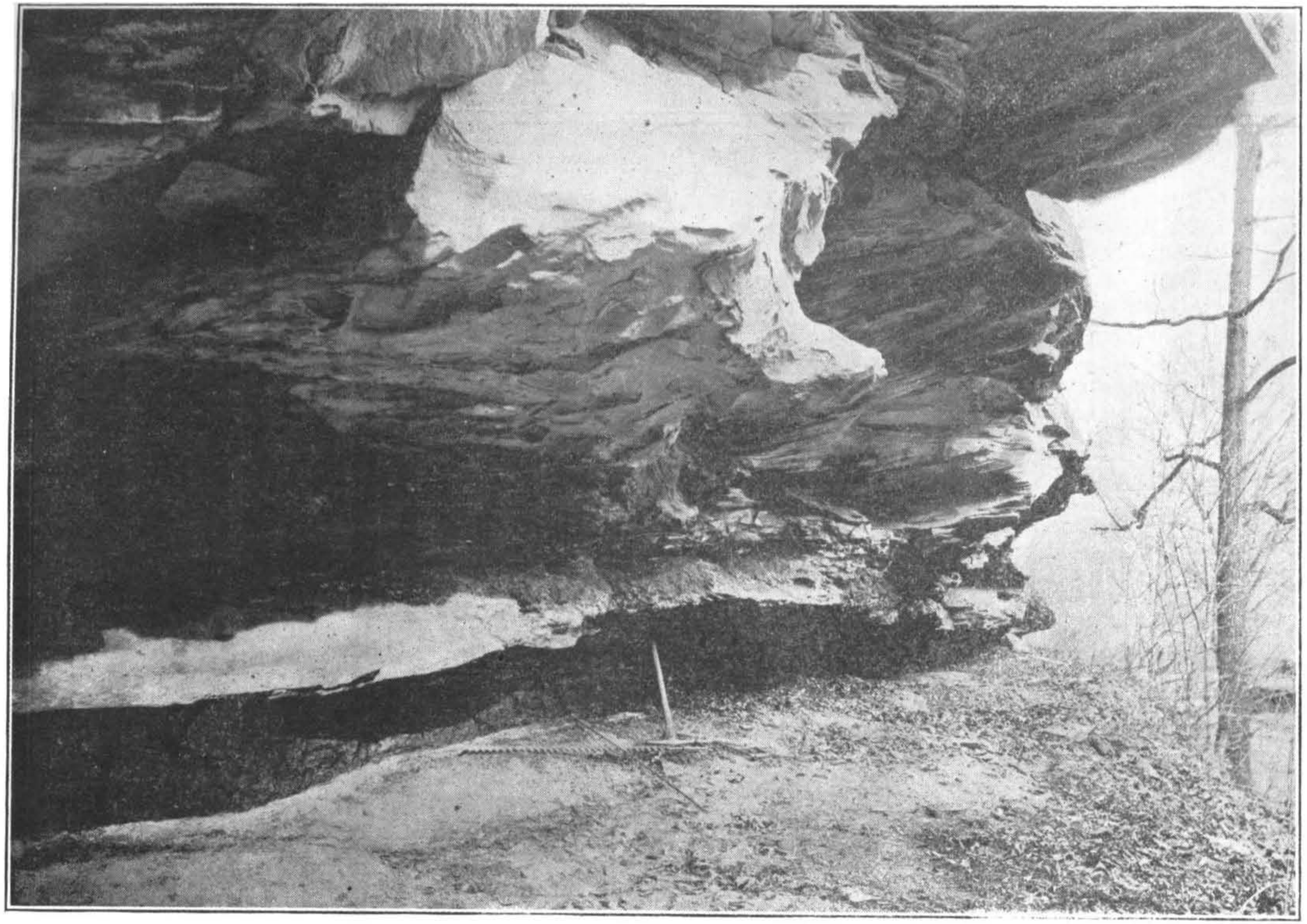
1921



THE WHITESBURG COAL AND SANDSTONE "ROCKHOUSE" ROOF.

This characteristic view of the well known Whitesburg coal and its superimposed thirty feet of cliff forming sandstone may be seen on Otter Creek just above its juncture with the Middle **Fork of the Kentucky River** in Perry County.

THE SIXTH GEOLOGICAL SURVEY

An Administrative Report of the Several Mineral Resource and General Geological Investigations Undertaken and Completed in Kentucky during the Biennial Period 1920-1921

By

WILLARD ROUSE JILLSON
DIRECTOR AND STATE GEOLOGIST

PRESENTED WITH TEN SEPARATE MISCELLANEOUS GEOLOGICAL PAPERS

BY

GEORGE P. MERRILL,
STUART WELLER
WILLARD ROUSE JILLSON
STUART ST. CLAIR
AND
CHARLES STEVENS CROUSE

Illustrated with 101 Photographs Maps and Diagrams

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THE KENTUCKY GEOLOGICAL SURVEY

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PREFACE

Applied geology is of great economic value to every State in which natural resources are only partly developed. This is especially true of Kentucky where the great body of mineral resources are now less than 20% under commercial operation. An ideal arrangement would be one where the State would have completed the base (topographic) mapping and the preliminary geological-resource surveys prior to the opening up of any oil, coal, natural gas, asphalt or other field. During the period of proving up such a field, State employed geologists could well work hand in hand with the operators, and assist them greatly in their efforts to win the resources desired.

Unfortunately this ideal arrangement has never existed in Kentucky, though it has to some extent in other States. With only 46% of Kentucky base (topographic) mapped, and with an area approximating that of sixty counties not covered by any accurate maps at all, the function of the Kentucky Geological Survey has always been crippled and held in restraint. The day of a 100% efficiency of the Kentucky Geological Survey seems yet to be in the distant future.

During the last biennium a large number of subjects of great economic value to this State have been investigated, however, by the Kentucky Geological Survey. A full account of these investigations is presented herewith in the first paper of this volume entitled, "The Sixth Geological Survey." A number of these economic papers are included within the covers of this book, and should assist materially in an understanding of the geology and resources of the several regions covered. This report is issued in an original edition of one thousand copies.

W. R. Jillson

Director and State Geologist.

Old Capitol,
Frankfort, Kentucky.
December 15, 1921.

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THE CUMBERLAND FALLS, WHITLEY COUNTY, KENTUCKY, METEORITE.[1]

By George P. Merrill

Curator of Geology United States National Museum.

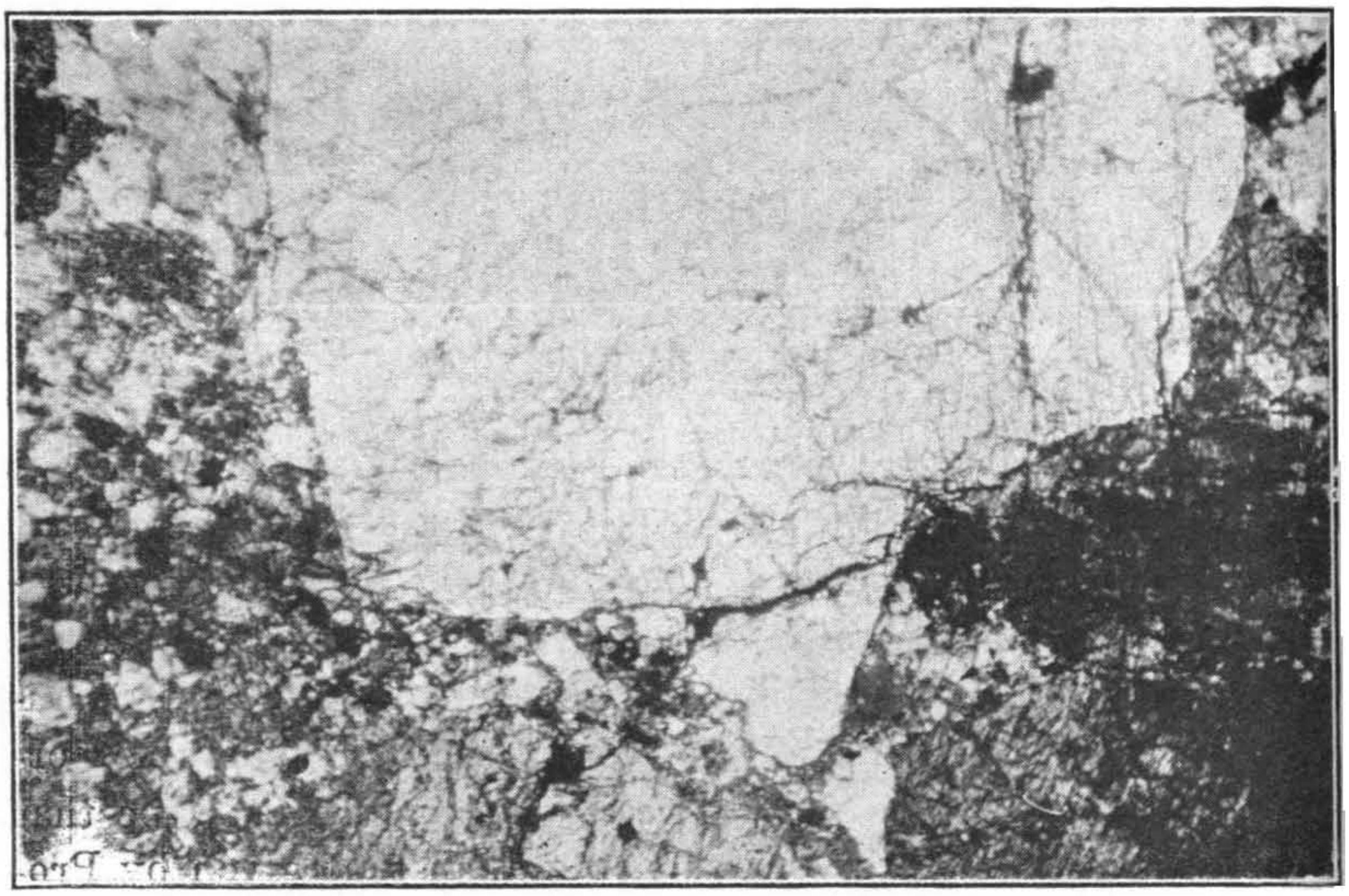
This stone which fell on the 9th of April, 1919, has been the subject of a note mainly descriptive of the fall,[2] by Prof. Arthur M. Miller, of Lexington, Kentucky, to whom the museum is indebted for his efforts in securing a considerable portion of the material.[3] The stone is of so unusual a type that it is worthy of more extensive notice than that given by Professor Miller, and fortunately the amount of the material secured is amply sufficient for the purpose.

On mere casual inspection there is little about the stone to suggest its ultra terrestrial nature. It is safe to say that had it not been seen to fall it would have been passed over even by one having a more or less intimate acquaintance with meteorites. On a broken surface it is of a light ash gray color, of a coarse texture, and might readily be mistaken for a terrestrial pegmatite in which the feldspar had undergone more or less whitening through weathering. Close examination reveals a pronounced brecciated structure produced by angular fragments of a chalky white mineral in pieces of all sizes up to 2 or more centimeters imbedded in a finer grey ground of apparently the same nature. Occasional inclosures of a dark gray-brown, almost black color, in one or two instances 3 to 5 cm. in diameter and angular in outline, exaggerate the pronounced brecciated structure which becomes so evident on a polished surface. Abundant flecks of a coal black, highly

[1] Reprinted from vol. 57, 1920, U. S. National Museum.

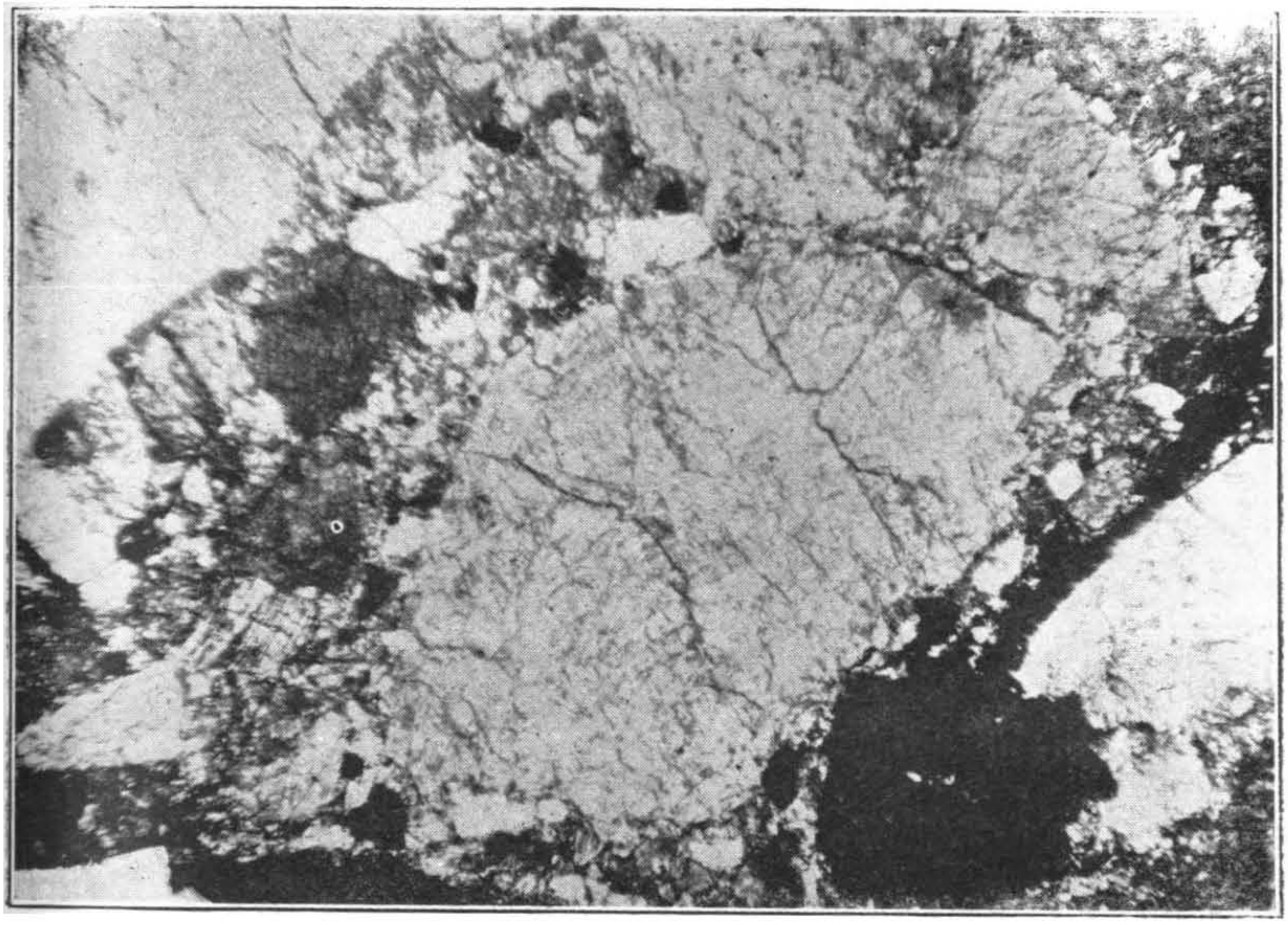
[2] Science, June 6, 1919; Also The Mineral Resources of Ky., vol. 1, ser. 5, No. 2, July 1919, pp. 110-114.

[3] Two complete individuals weighing respectively 567 and 23,478 grams and 13,476 grams of fragments. A 190-gram fragment was donated also by Mr. L. E. Bryan.



Microstructure, under low power, of the Cumberland Falls, Ky., Meteorite.

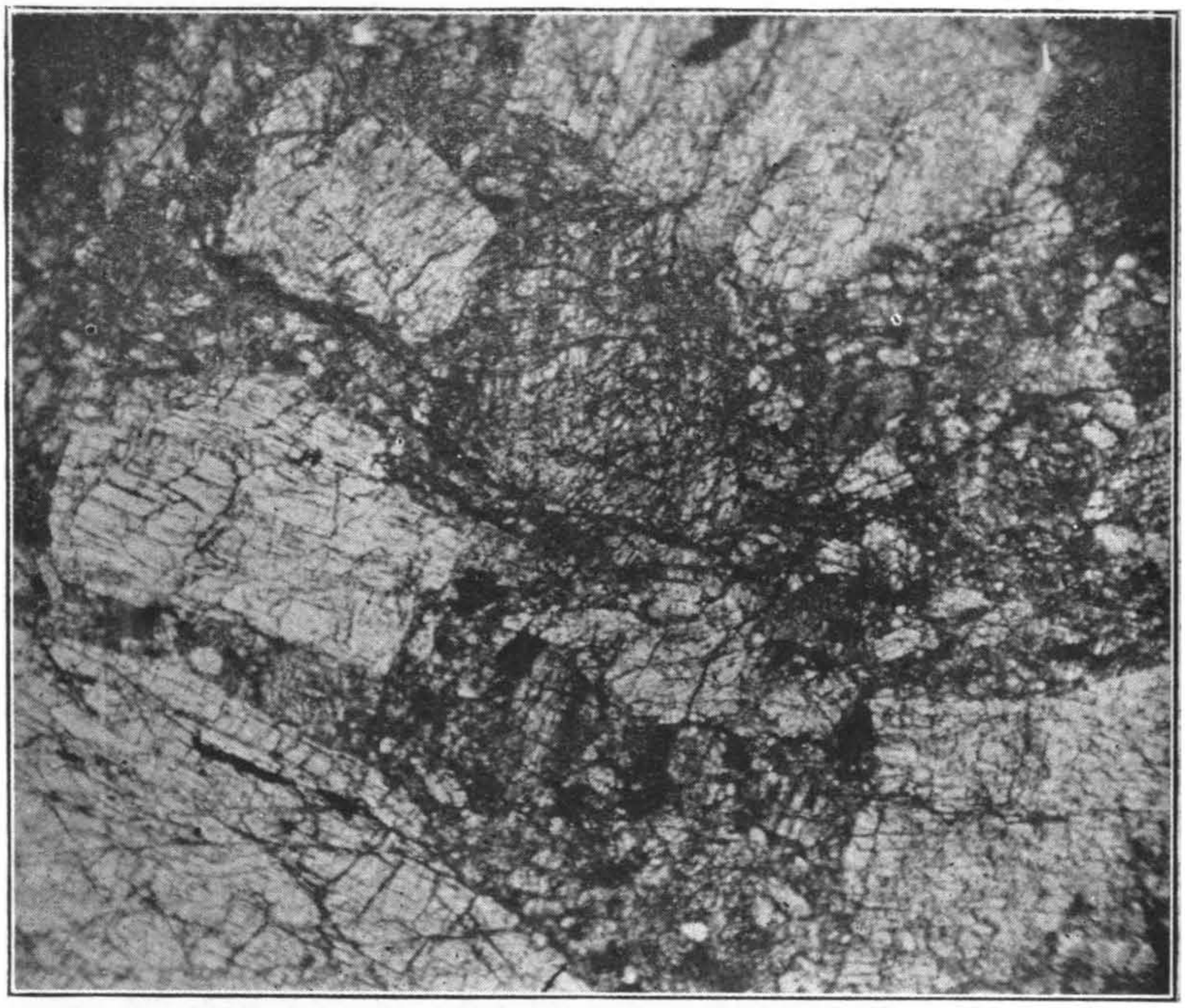
lustrous material are scattered irregularly through the ground, sometimes so abundant and of such small size as simply to render the rock dark gray in color, or again in shining blotches 10 to 15 mm. in diameter. Investigation shows these to be graphite. No iron or iron sulphide is noticeable on the broken surface and only abundant spots of newly formed iron rust suggest the presence of a ferrous chloride. The fusion crust or rind is inconspicuous of a yellowish to dirty yellowish-brown color, smooth and extremely thin—a mere skin coating. In several instances there was noted on freshly broken surfaces, small very thin areas of coal black or smoke-black glass. The cause of this or its relation to the crust is not readily apparent, but it is doubtless the very last fusion product of atmospheric resistance before reaching the earth. The usual pittings or thumb marks are present though the rock has become broken into so many pieces that these are not in all cases markedly evident. A local slickened movement is developed along the graphitic areas but which in no case observed extends throughout the mass. It would indicate



Microstructure, under low power, of the Cumberland Falls, Ky., Meteorite.

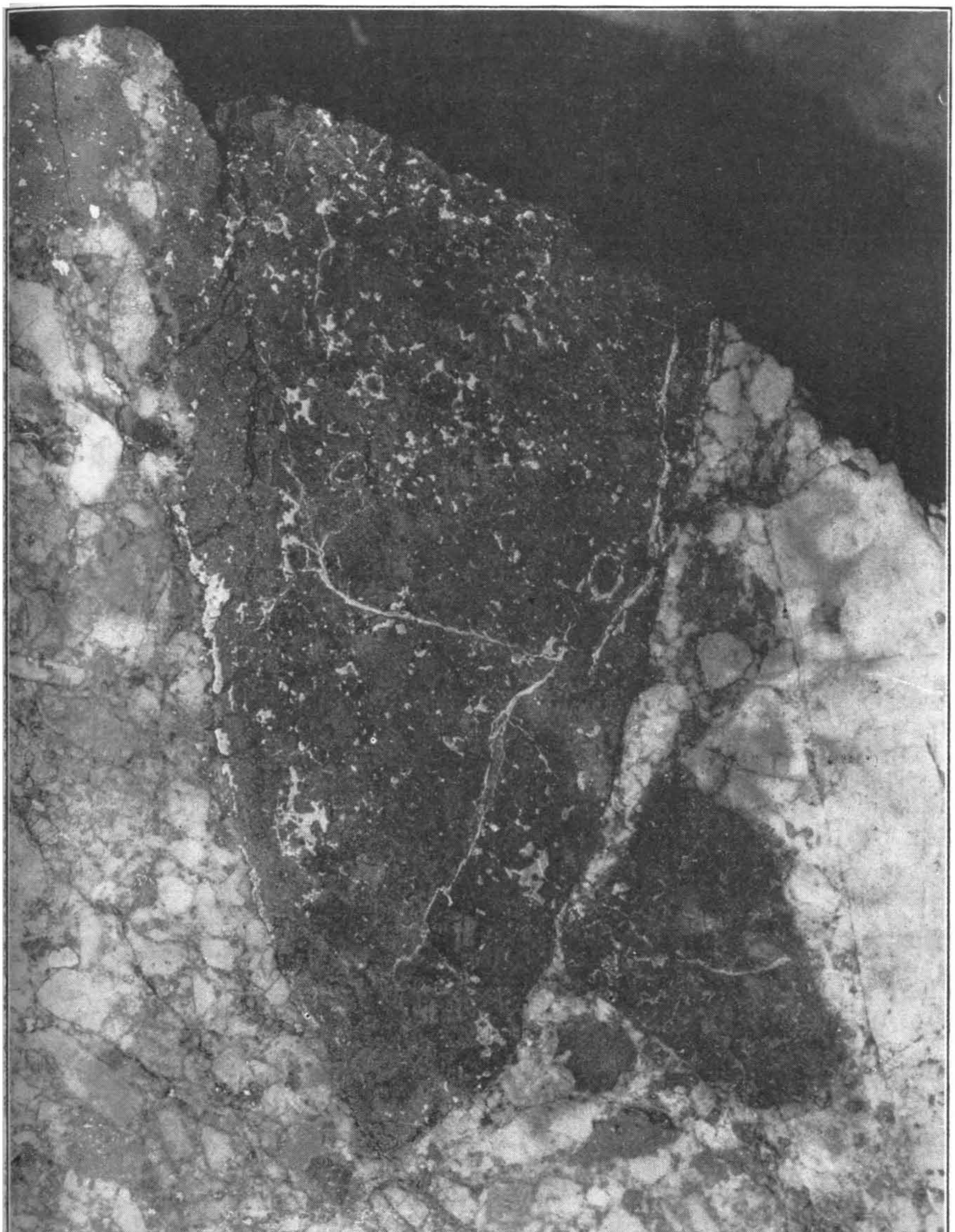
merely such a movement as would take place within a mass under compression, without the production of faults. On the polished surface scattered particles of metallic iron and iron sulphide are readily observed, but they are extremely irregular in their distribution, and much more abundant in the dark, nearly black enclosures referred to. An interesting feature is the peculiar weathered appearance of even a fresh fracture. Fragments broken through the impact of fall and gathered within a few days show dead, lusterless surfaces, as though exposed for many weeks or months. It is probable that this is due to the physical condition of the main constituents, noted later.

In the thin section the white, chalky mineral referred to is seen to make up the main mass of the rock, though in various conditions of fragmentation from almost perfect forms to mere dust. These are often so crushed, crumpled, and otherwise distorted as to give only undulatory extinctions, and with other optical properties badly obscured. More per-



Microstructure of the Cumberland Falls, Ky., meteorite illustrating the crushed and brecciated structure.

fect forms occur as broad plates with well-defined verticle cleavage lines giving parallel extinctions. Basal sections show imperfect, nearly rectangular prismatic cleavage and the emergence of an optic axis. These facts together with the refractive indices (1.658+) and the results of Mr. Shannon's analyses leave no question but that the mineral is enstatite. In many sections, however, the mineral shows in polarized light irregular, wavy, and interrupted bandings which extinguish alternately as the stage is revolved, in a manner at first suggestive of the polysynthetic twinning of monoclinic proxenes or feldspars. In these cases the broader more continuous bands give parallel extinctions and show in converged light the emergence of a bisetrix. The narrow, often indistinct and pinched out bands give inclined extinc-



MICROSCOPIC DETAIL OF METEORITE.
Dark enclosure shown in Pl II enlarged about 3 diameters. The light spots and streaks in the dark portion are metal.

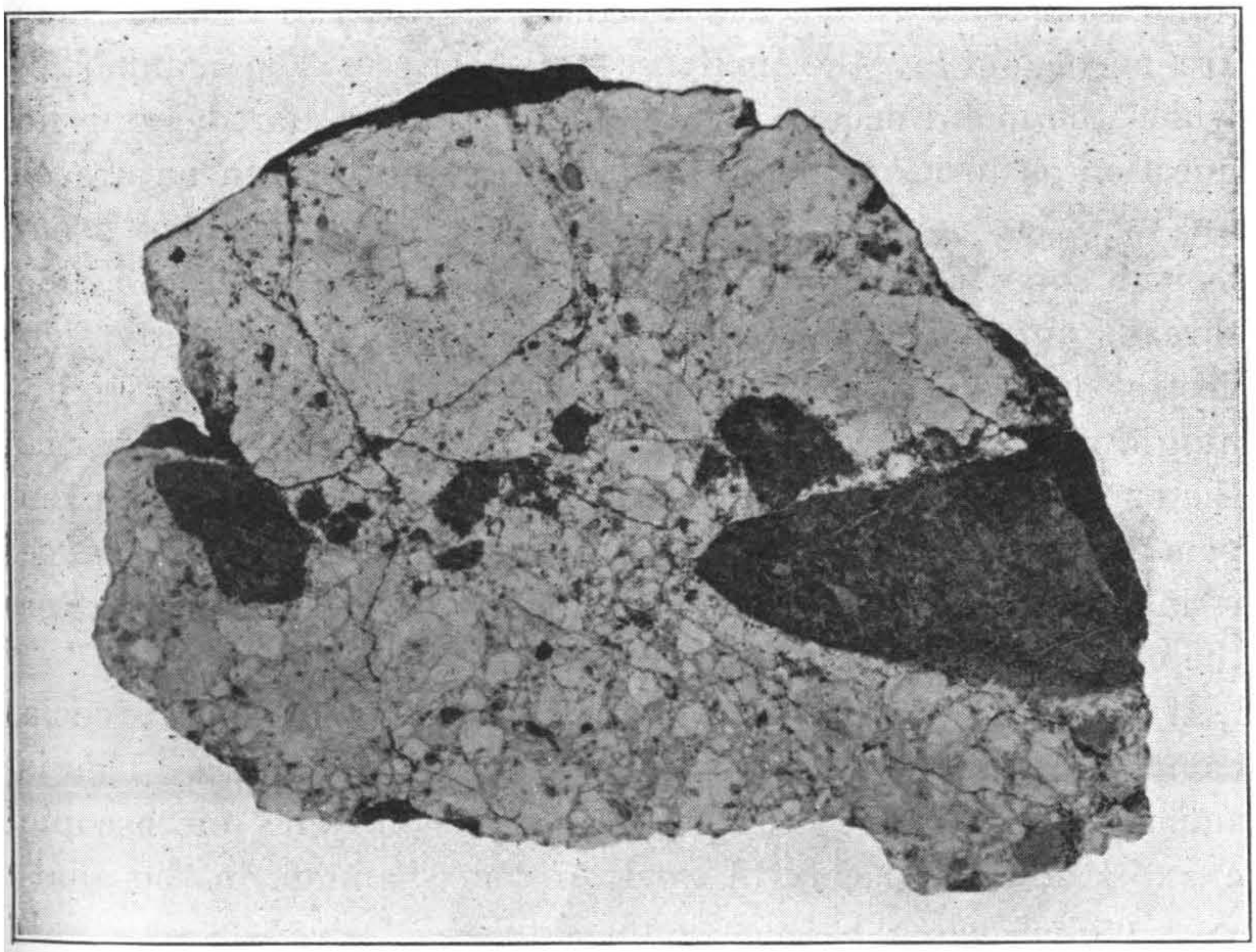
tions running as high as 37°. No distinction in color or refractive indices is noticeable, but there is apparently no question but there is here an intergrowth of orthorhombic and monoclinic forms in the usual manner. If the analyses made by Mr. Shannon correctly represents this intergrown material (it was selected and analyzed before such an intergrowth was suspected) the proportional amount of the monoclinic form as indicated by the amount of alumina and lime (1.09 Al_2O_3 and 0.96 CaO) must be very small. The extreme narrowness of the bands giving the inclined extinction is, however, at least partially confirmatory of this.

The chalky appearance of the mineral is plainly due to its physical condition, an abnormal development of the cleavage, which incidentally causes it to crumble away under slight pressure and makes it susceptible of being ground to powder in an agate mortar as readily as so much calcite. Whether this condition is due to the shock which resolved the original mineral into fragments is uncertain, but it would seem most probable. The failure to become recompacted under subsequent pressure might well be ascribed to a lack of moisture, pressure and dry heat alone naturally being less conducive to metamorphism.

In addition to the above, certain of the slides show intergrown with the enstatites in the form of small oval and irregular areas a brilliant polarizing mineral with the sharply developed platy structure characteristic of diallage. The mineral is also nearly colorless, with a very faint green tinge, and gives extinction angles measured against the edges of the plates; i. e. on clino-pinacoidal sections as high as 27°. The proportional amount of the diallage is quite variable, some slides showing only on accosional rounded granule and others several of the intergrowths mentioned.

Scattered irregularly throughout the mass of the rock are the scale-like segregations of graphite, above noted, sometimes several millimeters in diameter, in connection with which a differential movement has given rise to small areas with slickensided surfaces. In the finer portions, the graphite is

so evenly and finely diffused as to impart a dark gray color. Metallic particles are quite inconspicuous excepting on a polished surface, as are also those of iron sulphide. The relatively greater abundance of the metal and sulphide in the dark inclosures, above noted, is very evident on the polished surface. No calcium phosphate, maskelynite, oldhamite, osbornite, or other accessory minerals can be detected, although microchemical tests give rise to the usual globular ammonium-phospho-molybdate forms.



FRAGMENT OF CUMBERLAND FALLS METEORITE.
Cut and polished fragment of Comberland Falls, Ky., meteorite showing brecciated structure and dark enclosures.

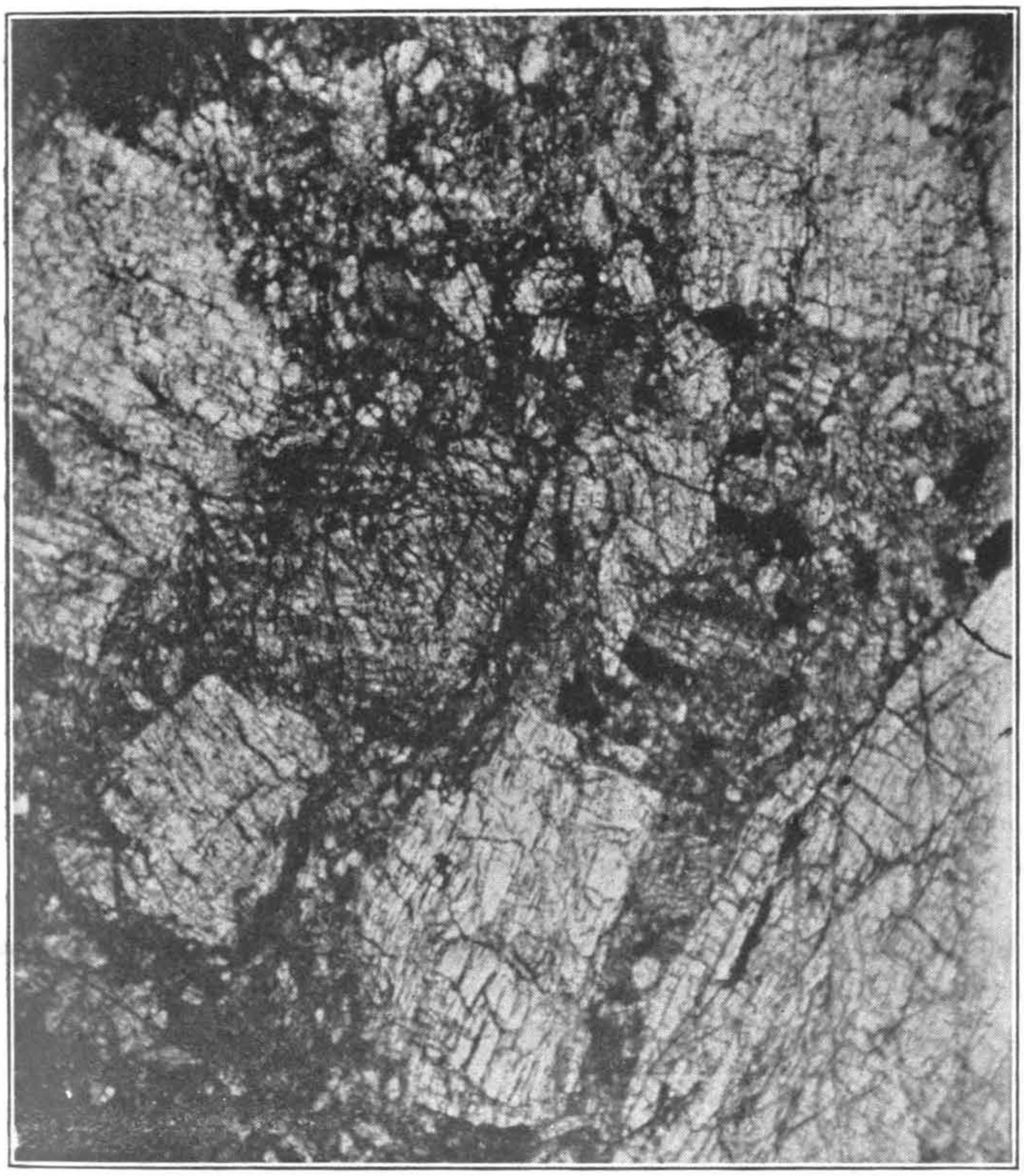
A close study of the dark inclusions developed some interesting and unexpected conditions. Examination with a pocket lens of the polished surface of one of the larger inclosures shown in plates 2 and 5 at once suggests a chondritic structure, a suggestion fully borne out by a study of the material in thin section, which shows a dark, obscure, and muddy ground containing numerous illy defined compressed and distorted radiating, barred, and nearly holocrystalline chondrules

of olivine and enstatite, mostly so obscured by a black impregnation that their true mineral nature is scarce recognizable. In these respects the structure so closely resembles that of the McKinney and Travis County, Texas, stones and others of Meuniers tadjerite group as to suggest a similar origin; that is, as developed from a normal chondrite (aumalite) through a process of heating. It is further to be noted that the dark portions are much richer in metal and, judging from the formation of abundant hydroxide of iron on a freshly cut or broken surface, richer also in ferrous chloride. These facts are borne out by the analyses noted later. The manner in which the metal occurs is interesting and peculiar, leaving no question as to its secondary origin and the foreign nature of the inclusion as well. One of these occurrences is shown enlarged some three diameters in plate 5, the metal in fine threads cutting across the surface in a manner strongly suggesting the figures sometimes given to show the play of lightning during a heavy electrical storm. Aside from these forms the metal at times completely surrounds a chondrule and even penetrates into it in the form of fine threads. The appearance is in entire accord with the idea of its late introduction after the crystallization.

It is evident at once that we have here a meteoric breccia composed of fragments of two quite dissimilar stones. This is sufficiently apparent from both megascopic and microscopic examination. The careful work of Mr. Shannon, in the analyses quoted below, is fully confirmatory.

CHEMICAL ANALYSES BY MR. E. V. SHANNON.

Before the intergrown nature of the pyroxenic constituents were suspected the clean chalky-white portion was carefully sampled, crushed, and separated from possible impurities by the mercuricioidide gravity solution. The results of an analysis of the powder thus obtained are given in column I below. In columns II and III are given for purpose of comparison previously reported analyses of enstatite from the meteorites of Bishopville, South Carolina, and Hvittis, Finland. The comparison with the enstatite of Hvittis, it will be noted, is particularly close.



Detail of Microscopic Structure of Cumberland Falls Meteorite.

Analyses of enstatite.

	Cumberland Falls.	Bishopville.	Hvittis.
	I	II	III
SiO_2	59.53	59.97	59.05
Al_2O_3	1.09	....	1.09
MgO	37.17	39.34	37.10
FeO	.98	.40	.90
CaO	.96	....	.98
(Ba, Sr)O	None.	Na_2O	.68
NiO	None.	K_2O.	.47
Loss on ign	.33	....	....
Total	100.06	99.71	100.07

Bulk Analyses of the Light (Major) Portion of the Meteorite.

A 70-gram fragment which, so far as could be judged, was representative of the gray brecciated portion of the stone, was selected and, through the courtesy of Dr. George Steiger, ground at the laboratory of the survey. This yielded as in column I below. Unfortunately Mr. Shannon was not present during the process of grinding and it is possible that a larger portion of small particles of the dark stone were incorporated in the mass than was surmised from the appearance of the fragment. The probability of this, which was not at first realized, is suggested by the slight excess of magnesia (MgO) and ferrous oxide (FeO) in the bulk analysis over that in the enstatite given above. In columns II, III, and IV are given for comparison previously published analyses of the Busti, Bishopville, and Shalka stones. It will be noticed that so far as the magnesium is concerned the Cumberland Falls stone agrees very closely with that of the first-named, although a trifle higher in silica.

	I	II	III	IV
Silica (SiO_2)	55.172	52.73	57.034	52.51
Alumina (Al_2O_3)	.382		1.706	.66
Chromic oxide (Cr_2O_3)	.062			1.25
Phosphoric oxide (P_2O_5)	Trace.			Trace.
Iron (Fe)	.888		.181	.25
Manganese (Mn)	.005			
Nickel (Ni)	.059		.039	
Cobalt (Co)	.004			
Copper (Cu)	.003			
Chromium (Cr)	Trace.			
Nickel oxide (NiO)	.123	.78	.538	
Cobalt oxide (CoO)	Trace.		Trace.	
Ferrous oxide (FeO)	2.916	4.28	1.265	16.81
Lime (CaO)	1.586	1.18	2.016	.89
Magnesia (MgO)	38.734	36.22	33.506	28.35
Manganous oxide (MnO)	.112	.01	.189	
Soda (Na_2O)	.157		1.027	.22
Potash (K_2O)	.150		.089	
Water (H_2O)	.167	Ign.	1.195	
Sulphur (S)	.784		.297	.14
Phosphorous (P)	.034			
Chlorine (Cl)	.028	[1] 2.35		
Carbon (C)	.164	[2] .92		
	101.530	99.47	100.023	100.08
Less O for (Cl, S, P)	.569		.147	
	100.961		99.876	

[1] $Na_2SCaSo_4CaCl_2$. [2] Ign.

The results given in column I seemingly bear out the microscopic determinations, and, in connection with the analysis of the white pyroxenic constituents given and warrant the conclusions drawn as to the mineral composition of the stone. It is to be noted, however, that qualitative tests show an unusually large proportion of silicate matter soluble in acid, and suggest the need of further chemical work. This must, however, be deferred for the present.

The 0.888 per cent of metal yielded:

Iron (Fe)	92.596
Nickel (Ni)	6.152
Cobalt (Co)	.417
Manganese (Mn)	.522
Copper (Cu)	.313
Chromium (Cr)	**Trace.**
	100.00

Bulk analysis of the dark chondritic inclosure, yielded:

Silica (SiO_2)	41.683
Alumina (Al_2O_3)	1.537
Chromic oxide (Cr_2O_3)	.591
Ferrous oxide (FeO)	9.399
Nickel oxide (NiO)	.211
Cobalt oxide (CoO)	trace
Phosphoric oxide (P_2O_5)	trace
Lime (CaO)	4.059
Magnesia (MgO)	27.848
Iron (FE)	12.108
Nickel (Ni)	.747
Cobalt (Co)	.078
Copper (Cu)	.001
Chromium (Cr)	trace
Manganese (Mn)	.088
Potash (K_2O)	trace
Soda (Na_2O)	trace
Chlorine (Cl)	.045
Sulphur (S)	2.464
Phosphorous (P)	.014
Carbon (C)	.449
Ignition (H_2O)	.210
	102.011
Less O for (Cl, S, P)	1.448
	100.563

In comparison with the other chondritic stones this offers no unusual features.

Treated with dilute hydrochloric acid (sp. gr. 1.06) and sodium carbonate solution in the customary manner the sili-

cate portion free from metal and metallic sulphide yielded 22.582 per cent of soluble matter of the following composition:

Silica (SiO_2)	38.239
Alumina (Al_2O_3)	trace
Ferrous oxide (FeO)	6.566
Nickel oxide (NiO)	.043
Manganous oxide (MnO)	.709
Cobalt oxide (CoO)	trace
Lime (CaO)	5.246
Magnesia (MgO)	49.197
	100.000

The 56.58 per cent insoluble silicates yielded:

Silica (SiO_2)	58.341
Alumina (Al_2O_3)	2.705
Ferrous oxide (FeO)	3.528
Nickel oxide (NiO)	.295
Cobalt oxide (CoO)	trace
Manganous oxide (MnO)	.562
Lime (CaO)	5.073
Magnesia (MgO)	29.496
	100.000

This bears out the somewhat unsatisfactory determination of the prevailing orthorhombic nature of the pyroxenic constituent, but the high (5.246) per cent of lime (CaO) is difficult to account for.

The 13.022 per cent metallic portion yielded:

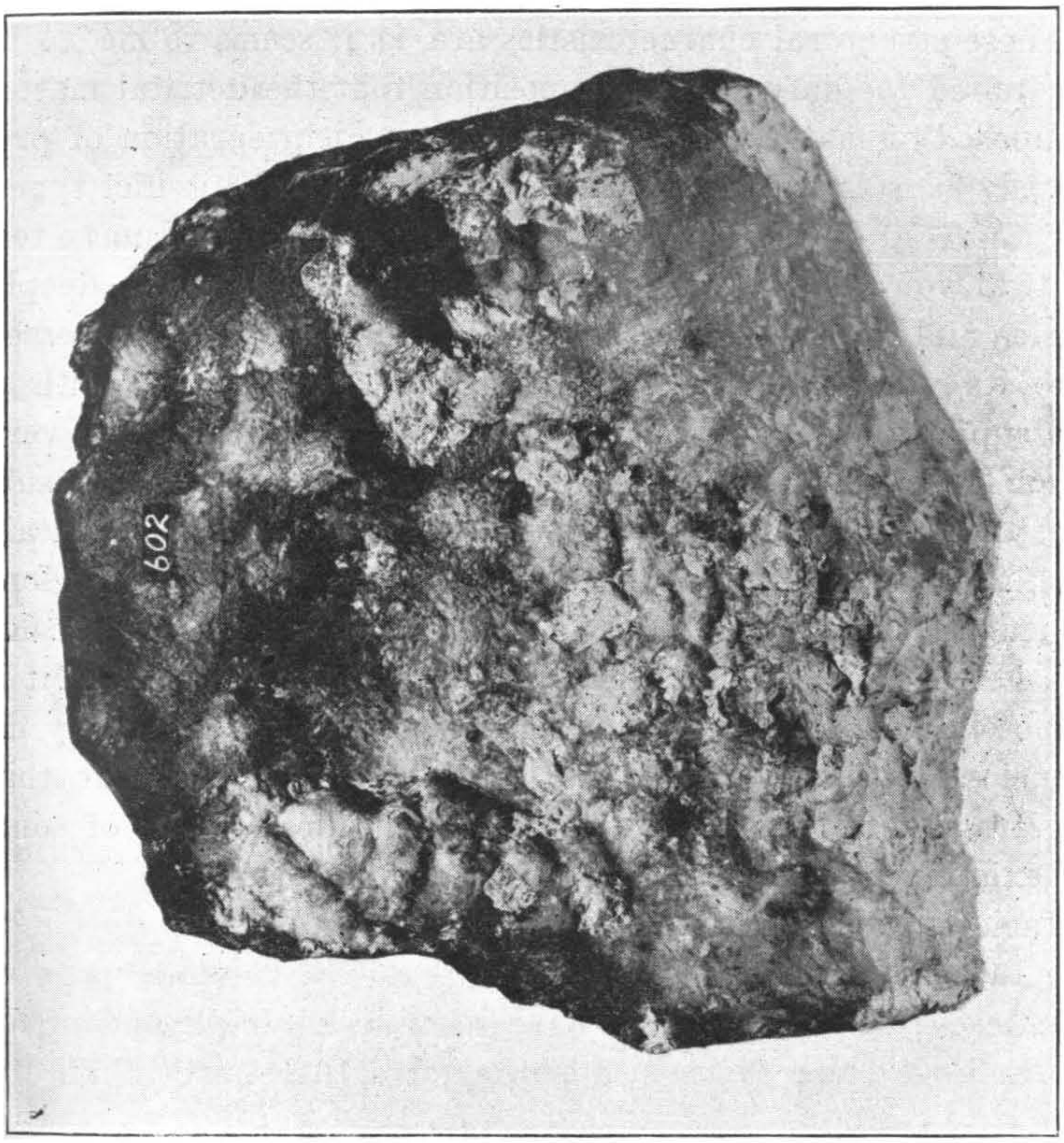
Iron (Fe)	92.982
Nickel (Ni)	5.735
Cobalt (Co)	.599
Manganese (Mn)	.676
Copper (Cu)	.008
Chromium (Cr)	trace
	100.000

The mineralogical composition of the dark inclusion as calculated from the foregoing is as below:

Metal	13.022
Troilite	6.760
Lawrenscite	.080
Chromite	.869
Soluble silicates mainly olivine	22.582
Insoluble silicates mainly pyroxenes	56.580
Carbon, mainly amorphous	.449
Calcium phosphate	trace
Water, hygroscopic	.210
	100.472

The most striking features of the stone, aside from its coarse brecciated structure, are the marked evidences of compression manifested in the numerous small slickensided surfaces and the crushed and optically distorted condition of the pyroxenes, as shown both in the hand specimens and in thin sections. It is to be noted that while the original shattering which resulted in the production of the fragments may have been due to impact or explosive action the mass has since been subjected to pressure under a heavy load whereby the particles have been further crushed and distorted and once more welded into a firm, rock-like mass. These are characteristics of deep seated terrestrial rocks that have been subjected to dynamic metamorphism.

The question naturally arises, is not the distortion so conspicuous in so much of the enstatite due to the crushing which resulted in the disintegration of the original meteorite rather than to any subsequent pressure? This question, I think, may be answered in the negative, though not with absolute certainty. The study of the sections shows that the line of contact between the light stone and the dark inclosures, while apparently sharp, is, as shown in the thin section, quite irregular, as a rule, particles from the one projecting into the other, though the superior hardness and toughness of the dark stone make this a less conspicuous feature than it might otherwise have been. Portions of the enstatite, are, however, jammed



A METEORITIC INDIVIDUAL.
This complete individual of Cumberland Falls meteorite weighed 2,347 grams.

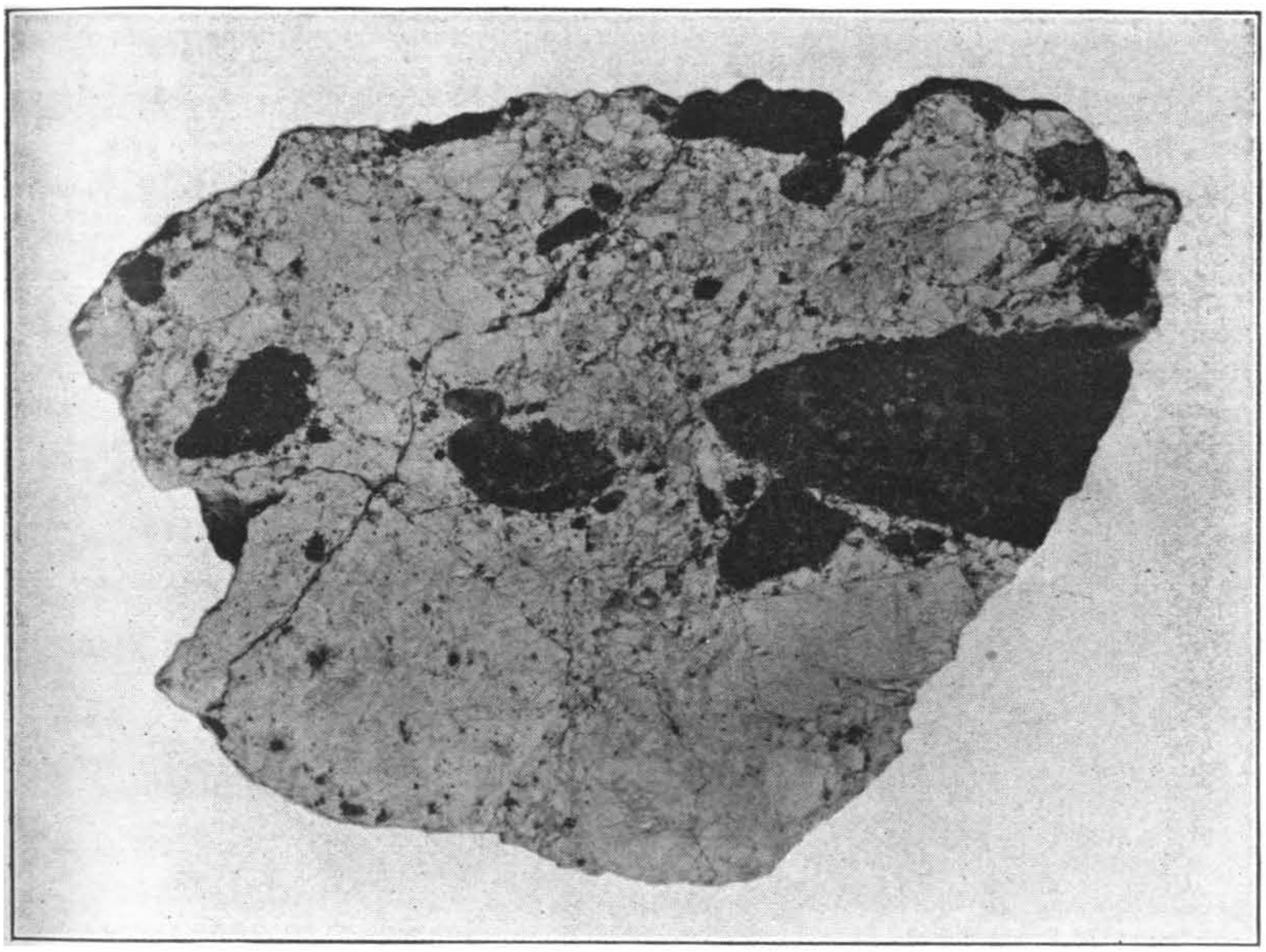
into the chondritic stone and particles of the chondritic stone into the enstatite as shown in the accompanying figure. In one instance where a section has been so cut as to cause one of these interpenetrations to appear as an inclusion in the chondritic stone, a minute fault can be traced cutting through both pieces and making itself conspicuous by a slight off-set. Apparently, the admixture of the two kinds of fragments took place prior to the evident compression and both stones were involved. The numerous slickensided areas sometimes of a few square centimeters dimensions further testify to the compression and condensation in mass which the stone has undergone.

These structural characteristics are, as it seems to me, to be accounted for only on the supposition that the detrital matter composed of materials derived from the disintegration of previously consolidated rock masses of at least two distinct types, accumulated on the surface as in the case of an ordinary terrestrial volcanic breccia. Subsequently the beds were deeply buried and through crustal movements the material compressed into its present condition. This supposition carries with it the supposition that the meteorite is but a spawl from a very much larger mass, one of such size, indeed, as to have been subject to such crustal movements as are incidental to mountain making and which find their terrestrial counterpart in regions of maximum disturbance, as in the steep synclinal folds of our southern Appalachians. How large such a mass must be it is impossible to say, but that it must have been of planetary dimensions would seemingly be a safe assumption. In fact, that the fragments are direct evidence of the destruction of some preexisting planet seems a legitimate conclusion.

Incidentally, it may not be out of place to call attention to the fact that this adds one more to the most acidic type of magnesia-rich stones which have been seen to fall and all of which have come to us in a period of a little more than 100 years.[1]

It must be evident from what has gone before that this stone has no exact counterpart among known meteorites and finds no exact place in the prevailing scheme of classification. Disregarding the inclosures of the chondritic stone it differs from the Bustites which chemically it closely resembles in carrying no appreciable amount of oldhamite, plagioclase, or osbornite and in its pronounced brecciated structure. From the chladnites it likewise differs in structure and its relatively high magnesia content. Nevertheless, it would seem more nearly related to these groups than others, though on the polished surface it suggests at first a remote similarity to the St. Michel stone described by Borgström and relegated by him

[1]See Merrill, G. P., The percentage Number of Meteorite Falls and Finds considered with Reference to their Varying Basicity. Proc. Nat. Acad. Sci., vol. 5, pp. 37-39, Feb. 1919.



A STUDY IN METEORITIC STRUCTURE.
Cut and polished fragment of Cumberland Falls, Ky., meteorite showing brecciated structure and dark enclosures.

to the rhodites. The Cumberland Falls stone, however, carries no chondrules. It is a breccia, as already noted, and its mineral composition, aside from the chondritic inclusion, is limited almost wholly to the enstatite with an intergrown monoclinic forms, sporadic diallage, and small quantities of metal, metallic sulphide, and graphite. In an attempt to make a position for it in the system of classification generally adopted,[1] I will suggest the name of *Whitleyite*, (Wht.), and define it as a coarse white to gray breccia composed chiefly of enstatite with minor quantities of diallage, metal, metallic sulphide, and graphite, and with sporadic inclosures of a black chondritic stone. The term Cumberlandite might have been selected, but that this name has been preempted by Wadsworth[2] for the terrestrial peridotite of Cumberland, Rhode Island. Whitley is the name of the county in which Cumberland Falls occurs.

[1] See Wulfing, pp. 446-460.
[2] Lithological Studies, p. 8.